Streams to demonstrate salmonid thermal exposure framework for Temperature Management

Overview

The amount of stream habitat available to anadromous fish in the California Central Valley has declined dramatically over the past 100 years. Due to the construction of large impassable barriers such as hydroelectric dams, accessible habitat has been reduced from ~10,000 stream kilometers to ~500km (CALFED 2005). This has severely affected anadromous fish populations in a variety of ways including displacement from historic spawning/rearing habitat, changes in thermal regimes, and an overall reduction in the amount of habitat for available spawning. Salmonids have been particularly affected by habitat alterations, reflected by the fact that their populations have undergone huge declines since the 1940's and 1950's. Chinook salmon runs which historically spawned at different times and places in watershed are now constrained to the small amount of habitat available in the tailwaters below dams. Spring-run Chinook runs have been extirpated in many rivers in the Central Valley possibly due to the inability to access high-altitude tributaries where they historically spawned. Now multiple runs compete for spawning and rearing habitat, perhaps resulting in unnatural strain for resources on populations. Additionally, managers may attempt to regulate flows and temperatures regimes that are optimized for a single run and or life stage; however, this may inadvertently inhibit another run or subsequent life stages. We here define the streams on which to demonstrate our Thermal Performance Curve Modeling framework and our rationale for selecting these particular streams. Our framework will give managers the knowledge necessary to optimize conditions for the most vulnerable life stages or runs in a given stream when ideal temperatures cannot be met year-round.

Stream selection – temperature availability

Our framework requires detailed knowledge of salmon phenology and distribution and temperature data for a particular river or stream segment. We first examined temperature availability of 22 candidate streams located in the California Central Valley (Table 1) that contain populations of anadromous Chinook Salmon. Observed mean daily temperatures were downloaded from the temperature monitors used in the NorWest project (downloaded from https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/StreamTemperatureDataSummaries.shtml) and used in our stream modeling project. Although we realize other water temperature data may be available from other sources for some Central Valley rivers, we focus on temperature data already compiled by the NorWest temperature database to avoid spending extensive amounts of time on data acquisition and QA/QC. Temperature date will be linearly interpolated between monitors to create continuous spatial temperature data along each stream, so streams that had fewer than two temperature monitors were not considered. We next examined the spatial distribution of spawners along each river to determine if the temperature interpolation would be inclusive of the spawning grounds (Fig. 1). Spawning distribution was estimated from our distribution dataset that will be used for another part of our project. Below, we list the available temperature data of each candidate stream.

American River: There are three temperature monitors along the American River.

Antelope Creek: Not enough temperature data.

Auburn Ravine: Not enough temperature data.

Battle Creek: Below the impassable fish barrier Whispering Falls, Battle Creek spans 47 km before entering the Sacramento River. Both spring and fall runs spawn at points along this stream. There are 24 temperature monitors, with mostly uninterrupted temporal data from ~2010-2015. Battle Creek is spring-fed.

Bear Creek: Not enough temperature data. Bear Creek only has two temperature monitors, and continuous temporal data for both of them was only available for about 1 year. Further, Bear Creek only has fall spawners. We will therefore not illustrate our framework on this stream.

Big Chico Creek: Not enough temperature data. The two temperature monitors for Big Chico do not overlap temporally.

Butte Creek: Butte Creek only has two temperature monitors, but continuous temporal data exists from ~2009-2015. Although the locations span most of the distribution of fall spawning, temperature data is not available for the majority of spring spawning, which stretches from ~ river km 30 (in Fig. 1) to the Centerville Diversion Dam.

Clear Creek: Clear Creek has 14 temperature monitors extending from the confluence with the Sacramento River (river km 29 in Fig. 1) to the Whiskeytown Dam (river km 0 in Fig. 1). The temperature coverage is excellent, spawning the entire spawning distributions of both spring and fall runs for >10 years. Of further interest, Clear Creek has been unable to meet salmonid spawning temperature criteria of ≤13.3°C (56°F) for over 75% of the spawning season in 7 of the past 9 years (CCTT 2017).

Cosumnes River: Not enough temperature data. We had originally suggested the Cosumnes River to illustrate our framework. However, there is no temperature data along this river in the NorWest database. Further, the Cosumnes River is an unregulated, large river, and does not seem to support any wild runs.

Cottonwood and S. Fork Cottonwood Creeks: Not enough temperature data. Only two temperature monitors exist, and these do not include the majority of fall spawning distribution.

Cow Creek: Not enough temperature data.

Deer Creek: Deer Creek spans approximately 100 km before emptying into the Sacramento River. The temperature data spans the spawning distributions of both spring and fall run, but there is little continuous temporal overlap.

Feather River: Not enough temperature data. The Feather River had two temperature monitors, but they were far downstream of spawning grounds.

Merced River: Not enough temperature data. The Merced River had two temperature monitors, but they were far downstream of spawning grounds.

Mill Creek: Not enough temperature data

Mokelumne River: Not enough temperature data

Sacramento River: We examined temperature availability below Keswick Dam for 253 km, representing the furthest downstream temperature monitor that included all winter and fall spawners. The Sacramento River does not have spring spawners. Continuous temperature data that encompasses the entire spawning distributions of both fall and winter runs exists only for 2009 from the temperature monitors used in the Norwest project.

San Joaquin River: There are lots of temperature monitors for the San Joaquin River.

Stanislaus River: Spring and fall runs can access 94 km of the Stanislaus River, from where it enters the San Joaquin River (river km 149 in Fig. 1) up to the impassible fish barrier Goodwin Dam (river km 56 in Fig. 1). The Stanislaus River has fairly good temperature coverage just below Goodwin Dam and downstream near the San Joaquin River, encompassing the entire spawning distributions of spring and fall runs. We therefore plan to analyze the Stanislaus River.

Thomes Creek: Not enough temperature information. Thomes Creek does have two temperature monitors, but they are far upstream of spring spawning grounds.

Tuolumne River: The Tuolumne River currently only has fall spawners; spring run has been extirpated. Temperature coverage spanning fall spawning distribution is excellent, and is fairly good for most of the river below La Grange Dam (river km 4 in Fig. 1) to its entrance into the San Joaquin River (river km 90 in Fig. 1). Because of its excellent temperature coverage, we will use this river as an example of a river where spring run has been extirpated.

Yuba River: We had originally planned to examine the Yuba River, and much of our preliminary work was focused on this river. However, there are large temporal gaps in the temperature data. This river may be more useful if analyzing a specific year that has temperature data.

<u>Stream selection – distribution and phenology data availability</u>

We next determined if phenology data was available that coincided with temperature data for Clear Creek, Stanislaus River, and Tuolumne River. These three rivers have good temperature coverage and represent a variety of scenarios (discussed below). Specifically, we searched for spawning information from carcass and redd surveys for years with continuous temporal data.

Clear Creek (spring run): Redd and carcass survey data for spring run are available from Clear Creek from 2003-2007 (Giovannetti and Brown 2007). Clear Creek spawning grounds and juvenile rearing for spring run are known (AFRP 2015). Approximate adult holding times along this creek are also documented (CCTT 2017).

Clear Creek (fall run): Daily escapement surveys based on video monitoring are available for 2012-2017 (Killam et al. 2013, 2014, 2015, 2016, 2017). Weekly carcass surveys were conducted in 2004 (Inland Fisheries 2006). Clear Creek spawning grounds and juvenile rearing for fall run are also known (AFRP 2015), with recent efforts made to segregate spring and fall spawners using a temporary picket weir (Killam et al. 2014).

Stanislaus River (fall run only): Daily documentation of adult escapement at the Stanislaus River weir is available from 2003-2008 (FISHBIO 2010) and 2011-2016 (FISHBIO 2017).

Tuolumne River (fall run only): Chinook redd surveys occurred along the Tuolumne River 2012-2013 (FISHBIO 2013). Daily documentation of adult escapement at the Tuolumne River weir is available from 2011-2016 (FISHBIO 2017).

Final stream choices

Taking into consideration the availability of temperature data, Chinook run timing and spatial distribution, and the availability of phenology data, we select the following streams to illustrate our Thermal Performance Curve modeling framework: Clear Creek, Stanislaus River, and

Tuolumne River (Fig. 2). We chose these streams to cover a breadth of run scenarios, amount of available habitat (measured in river km), and flows. Clear Creek has both fall and spring runs, whereas the Stanislaus and Tuolumne Rivers currently only have fall run because spring run have been extirpated. These streams also represent different amounts of available habitat for salmon: less than 50 km for Clear Creek, and 50-100 km for Stanislaus and Tuolumne Rivers. Clear Creek has a low mean annual flow, Stanislaus has a moderate flow, and the Tuolumne has the highest flow. As per the steering committee's suggestion, these streams are all regulated by hydroelectric dams, allowing for a controllable response based on scientific information.

Potential analyses of other rivers

We chose to illustrate our framework on Clear Creek, Stanislaus River, and the Tuolumne River in order to demonstrate how our modeling may be applied rivers of different scenarios. We stress, however, that our framework may be applied to any stream or river as long as distribution, phenology, and temperature data are available. In particular, Battle Creek, Sacramento River, and San Joaquin River have good or fairly good temperature availability, and we will try to analyze these streams, time permitting. Battle Creek has great temperature data from ~2010-2015, but is an unregulated, spring-fed stream, so analyzing Battle Creek would not facilitate flow regulation management along this stream. However, modeling of Battle Creek would show how a Central Valley stream naturally functions without a large dam. Further, there is interest in Battle Creek as a potential site to reintroduce the endangered winter run. Due to recent increases in flow, spring run fish have returned to spawn in the main stem San Joaquin for the first time in 60 years; applying our framework to pre- and post-spawning years will help elucidate if temperature changes – alongside increasing flow – are helping to re-establish this population. The temperature data from the NorWest monitors along the Sacramento River has large temporal gaps; however, the SWFSC has temperature data from this river that is already QA/QC'd, which may decrease the temporal gaps. Application of our framework to the Sacramento River would be interesting as this is the only river that hosts spawning winter run Chinook.

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Table 1. Candidate list of 22 streams in the Central Valley. Our selected rivers are highlighted. Temperature monitors are from NorWest. # km indicates the number of km examined, usually to an impassible fish barrier.

River	Fall	Spring	# Temp monitors	# km	Regulated	Migration Data	Spawn Data	Juvenile Data	Disease Data	Data Type
American River	X	O	3		X		X	X		Carcass survey, redd survey, screw trap
Antelope Creek	X	X	0			X	X			Snorkel survey, redd, bio survey, video monitoring
Auburn Ravine	X		0		X		X			Redd survey, gaps in yearly monitoring
Battle Creek	X	X	24	47						Carcass survey/ Snorkel redd survey, hatchery counting,
Bear Creek	X		2	37		X				Video monitoring
Big Chico Creek	X	X	2	83			X	X		Snorkel/Carcass survey, rotary screw trap
Butte Creek	X	X	2	169	X	X	X	X		Carcass survey, snorkal survey, video monitoring, rotary screw traps
Clear Creek	X	X	14	29	X	X	X	X		Redd/Carcass survey, Video monitoring, rotary screw traps
Cosumnes River	X		0				X	X		Carcass survey, screw trap, gaps in yearly monitoring
Cottonwood Creek	X	X	2			X	X	X		Carcass survey, Video monitoring, seine and rotary screw traps
Cow Creek	X		1	90		X	X			Video monitoring, carcass survey
Deer Creek	X	X	6	120		X	X	X		Carcass/redd survey, snorkal, video survey
Feather River	X	X	2*	125	X		X	X	X	Redd survey, carcass survey, screw traps, snorkal survey
Merced River	X	O	4*	277	X		X		X	Carcass survey, fish distribution/redd counts
Mill Creek	X	X	1	104		X	X	X		Carcass, redd, snorkal, video survey, rotary screw trap
Mokelumne River	X	O	0	159	X	X	X	X		Video trap and monitoring, carcass survey, redd count/distribution, screw trap
Sacramento River	X	O	7	253	X	X	X	X	X	Carcass survey, redd survey, screw traps, snorkal survey
San Joaquin River	X	X	lots	568	X	X	X	X	X	Redd survey, carcass survey, screw traps, snorkal survey
Stanislaus River	X	O	7	93	X	X	X	X	X	Carcass survey, redd distribution, weir video monitoring, snorkal, seine, tagging
Thomes Creek		X	2*	145						
Tuolomne River	X	O	28	86	X	X	X	X	X	Carcass survey, redd distribution, weir video monitoring, snorkal survey, beach seine, rotary screw trap
Yuba River	X	X	~5	74	X		X	X		Carcass survey, Redd survey, limited screw trap data

*Temperature monitors are far upstream or downstream of spawning grounds

Figure 1. Temperature data availability for selected streams in time (X-axis) and space (river km on Y-axis). Approximate spawning distributions for spring (gold) and fall (green) are shown.

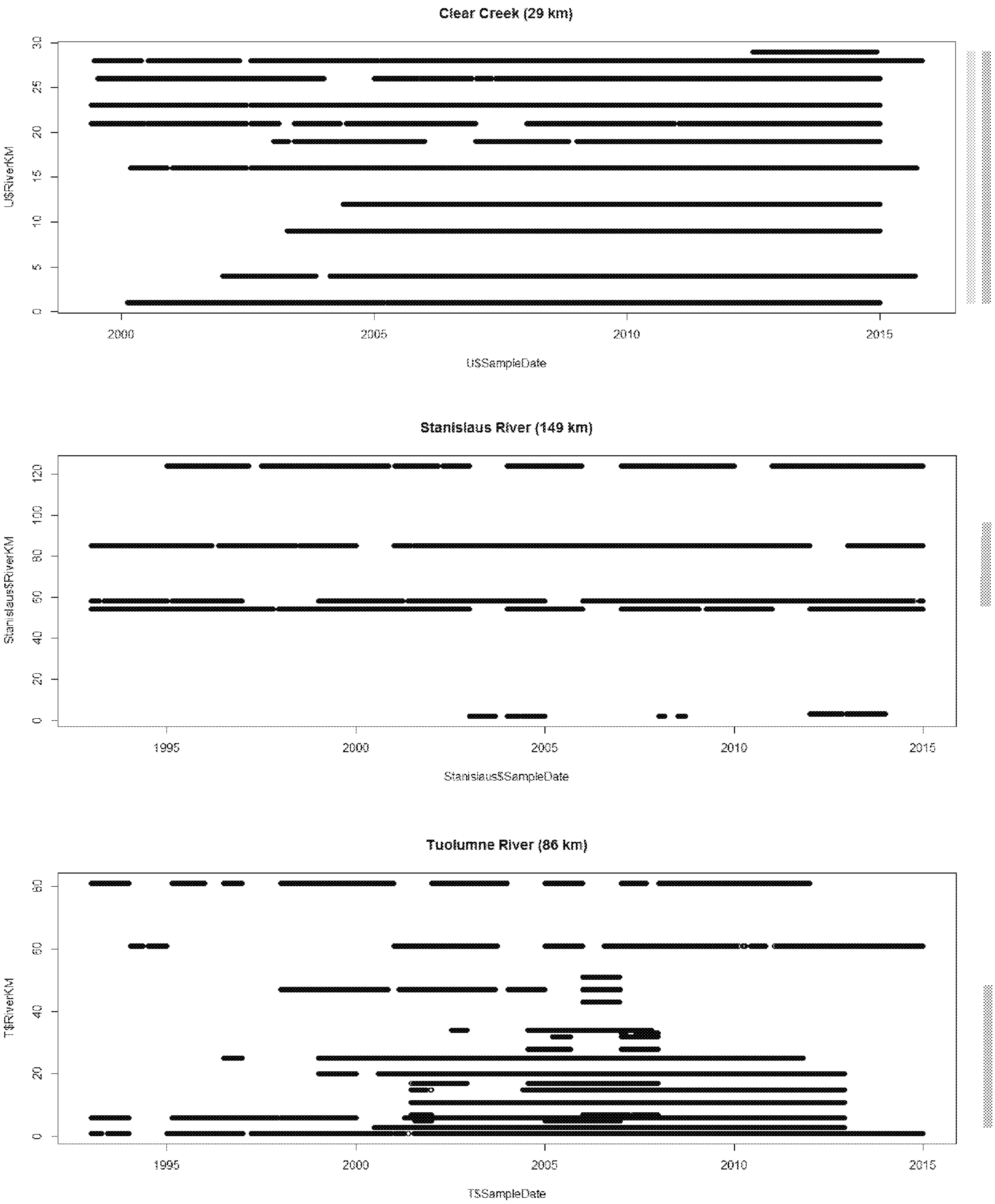

Figure 2. Selected (Clear Creek, Stanislaus River, Tuolumne River) and potential (Battle Creek, Sacramento River) rivers (dark blue), and spring run (gold) and winter run (purple) spawning distributions. All five rivers have fall run (not shown). Spring run have been extirpated along the Tuolumne, Stanislaus, and Sacramento Rivers. Analyses will be run on the available habitat to salmon, below impassible barriers (red crosses). Rivers are shown against a backdrop of Central Valley stream temperatures (preliminary results) for September, the peak month of spawning for spring run. Temperatures range from 9.8°C (blue) to 26°C (red).